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Concrete Mix Proportions with Ultra-High Electrical Resistivity

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ABSTRACT

Durability is the ability of concrete to withstand any deterioration process during its service life. Different concretes require different degrees of durability depending on the exposure environment and properties desired. The long-time behavior of concrete structures has shown that their main cause of distress is reinforcement corrosion. This type of damage is responsible for the huge financial cost spent each year on the repair of deteriorated structures.

The electrical resistivity of concrete is one of the main parameters controlling the initiation and propagation of reinforcement corrosion specially in railway ties or in structures in which concrete is used for protection from stray currents. Electrical resistivity is well correlated with durability parameters such as diffusion coefficient, capillary absorption and porosity.

The main aim of this study is achiving to ultra high electrical resistivity in concrete; in this paper, bulk electrical resistivity of concrete is measured using a new instrument in which bulk electrical resistivity is calculated in different frquency ranges. The effect of silica fume and metakaolin as pozzolanic admixtures has been investigated. Also the effect of aggregate content types is studied in this research.

KEYWORDS

Electrical Resistivity, Metakaolin, Silica fume

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1 INTRODUCTION

Corrosion of steel reinforcment is responsible for premature deterioration of concrete structures worldwide, particularly in marine environment of hot regions such as Persian Gulf. It is well known that the durability of materials and structures depends both on the environmental conditions at the exposed surfaces of the structures and on the material resistance to the action of aggressive substances [Antonio Costa and Julio Appelton 2002].

Electrical resistivity is an important durability characteristic of concrete to resist the passage of electrical current and it may directly affect the rate of steel corrosion. This would be of more importance in electrically powered rapid transit lines, where high resistivities are required.

Electrical resistivity is fundamentally related to the permeability of fluids and diffusivity of ions through porous materials such as concrete. Therefore, electrical resistivity also can be used as an indirect measure of the ability of concrete to prevent penetration of chloride salt solutions that may cause corrosion of the reinforcing steel [David A. Whiting and Mohamad A. Nagi 2003].

In other words, electrical resistivity may be considered as a function of concrete quality and pore structure. Consequently parameters such as water to cement ratio, cement content, cement type, pozzolanic materials, compaction, curing period, age of concrete may affect electrical resistivty.

In the case of metals embedded in concrete, the electrolyte for the corrosion cell is the concrete itself. A resistivity of less than 5 K.Ohm.cm can support very rapid corrosion of steel [Brown, 1980]. If the electrolyte has high resistance to the passage of current, or if the electrolyte is dry and unable to support ionic flow, then corrosion will occur only at a very low rate, if at all. Various researchers [Tremper, 1958; Vassie, 1980; Alonso et al., 1988] have determined that corrosion can be limited by increasing resistivity. A table of suggested values [Langford and Broomfield, 1987] is shown in Table 1.

When resistivities exceed a value of 20 K.Ohm.cm the risk of corrosion is low. Where steel is actively corroding, however, Broomfield et al. [1993] state that resistivity must exceed 50 K.Ohm.cm to reduce corrosion to an acceptable rate, and that resistivity must exceed 100 K.Ohm.cm to stop corrosion entirely.

Table 1. Relationship between resistivity and corrosion rate of steel in concrete

Electrical resistivity (KΩ.cm)	Corrosion rate
<5	Very High
5-10	High
10-20	Moderate
>20	Low

Purpose of this study is to increase the bulk electrical resistivity of concrete in laboratory condition. The effect of cementitous materials, aggregate content, and different pozzolans on electrical resistivity are investigated using a new commercial electrical resistivity-meter.

2 EXPERIMENTAL INVESTIGATION

2.1 Materials

The cementitious materials used in this study were Portland cement (PC) equivalent to ASTM Type II, silica fume (SF) obtained from Azna ferro-silicon alloy manufacture. Metakolin used in this research

was provided from ASAN SERAM Company, Iran. The chemical composition of the Cement, Silica fume and Metakaolin are given in Table 2.

Table 2. Chemical composition of Metakaolin, cement and silica fume.

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	P_2O_5	L.O.I
Metakaolin	51.85	43.87	0.99	0.20	0.01	0.12	0.18	1.74	0.03	-
Cement	22.42	4.68	3.68	63.2	0.25	0.75	3.63	-	-	0.45
Silica Fume	93.16	1.13	0.72	-	-	-	1.6	-	-	1.58

Silica aggregates were provided from Techno-Silica plant, Iran. Polycarboxylate ether polymer superplasticizer and lignosulphonate plasticizer were used for the mixes in order to improve the workability of fresh concrete.

Aggregates with maximum size between 12-19 mm must be used for preparing ordinary concrete. Therefore, S-curve graph has been served for optimized grading, also the cost of raw aggregates and the quality of aggregate packing is to be optimized [Genadij Shakhmenko and Juris Birsh 1998] (shows in ‘Fig. 1’).

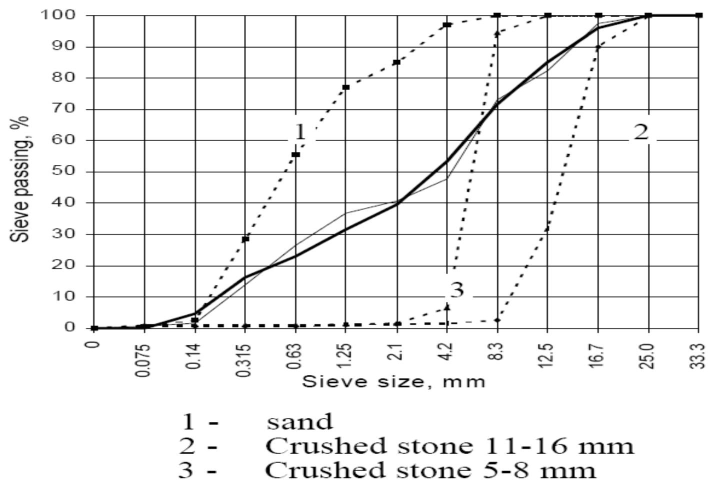

Figure 1. S-Curve for grading aggregates.

2.2 Mix proportions

Concrete of 6 different mix designs were selected among many mix designs studied during the research program. The mixes are presented in Table 3. Fine and coarse aggregates were used in 30% and 70% proportions, respectively.

2.3. Sample Preperation, Casting and Curing

Three specimens were made for each mix proportion. Concrete of each mix was casted into 10 cm cubic molds. In order to reduce void space, compaction was done using a steel tamper in 4 layers, each layer compacted by 30 impacts. The molds were covered with the burlap kept wet for 24 hours after casting. The specimens were removed from the molds and were allowed to cure in water saturated with calcium hydroxide at 80 °C for 28 days. Specimens were tested for the electrical resistivity at the ages of 7, 14, 21 and 28 days.

Table 3. Details of concrete mixtures

Materials	Mix					
	1	2	3	4	5	6
Cement (kg/m^3)	600	550	550	400	650	650
Water (kg/m^3)	300	250	250	200	350	350
W/C ratio	0.5	0.45	0.45	0.5	0.5	0.5
Silica-fume (kg/m^3)	400	320	350	320	-	350
Metakaolin (kg/m^3)	250	230	180	135	350	-
Cementitous Materials (kg/m^3)	1250	1100	1080	855	1000	1000
Aggregates (kg/m^3)	900	1100	1100	1350	1100	1100
SP (% by weight of cement)	1	1	1	1	1	1

It has been found that hot water curing will accelerate electrical resistivity growth [David A. Whiting and Mohamad A. Nagi 2003]. It seems specimens with smaller amount of cementitiuos materials have higher growth in resistivity at the end of the curing period.

2.4 Test Procedure and Measurement

Sudden temperature variations may lead to microcracks in concrete. To prevent initiation of microcracks, temperature of specimens should be slightly declined a few hours before testing. Specimens were tested at saturated surface dry condition.

It's important to dry the surface before testing as the moist surfaces may cause resistivity declining and inaccurate measurement. After drying the surfaces, electrical resistivity of concrete has been determined by two cuprous plates. Sufficient fresh cement paste has been injected between cuprous plate and specimen surfaces for complete connection (as shown in 'Fig. 2').

The new instrument innovated in Construction Materials Institute has been applied. It should be noted that the alternative current has been used in testing procedure and the resistivity hase been determined by measuring the respective voltage. The device which is shown in the follwing picture Measures the bulk electrical resistivity of concrete by providing measurement in different frequency ranges.

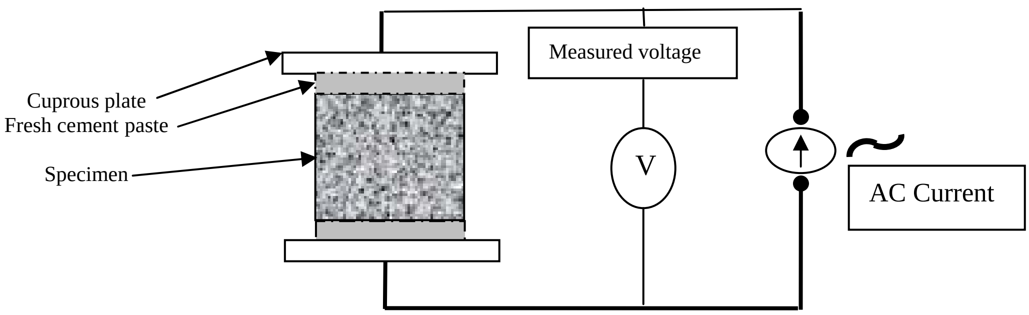

Figure 2. schematic diagram of testing procedure

3 RESULTS AND DISCUSSIONS

3.1 Results

The Results of the electrical resistivity of are illustraed in Table 4. Values are avarage of the three specimens of each mix design.

Table 4. Electrical Resistivity of specimens at the ages of 7,14,21 and 28 days

Age (days)	Electrical Resistivity (K.Ohm.cm)						
	Mix	1	2	3	4	5	6
7		1930	1970	5880	8340	17	600
14		3040	4940	8160	16590	46	1350
21		6460	8510	10130	18090	163	3340
28		7000	11090	17610	18500	217	3730

The above results in Table 4 compared with Table 1, show that concrete with ultra-high electrical resistivity has been gained.

3.2 Disscussions

3.2.1 Effect of Aggregates Content

According to the Figure 3, increasing the aggregate contents can accelerate the electrical resistivity. The electrical resistivity of aggregate is much higher than that of cement paste. While there is no specific study on the effect of aggregate type on electrical resistivity of concrete, one would expect that resistivity of concrete made with limestone aggregate would be less than that of concrete made with silica aggregate [David A. Whiting and Mohamad A. Nagi 2003].

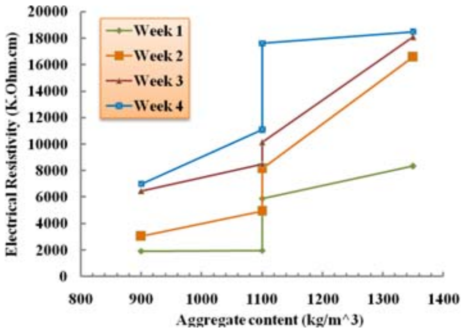

Figure 3. Relation between aggregate content and electrical resistivity

3.2.2 Effect of Cementitious Materials

Supplementary cementing materials such as silica fume and metakaolin have been used in concrete production of this research in relatively large amounts to improve durability charactersitics of concrete. Because of their pozzolanic effect and their physical properties, these materials improve microstructure of the cement matrix, and reduce concentrations and mobilities of the ions in the pore solution. Therefore they exert an influence on the electrical resistivity of concrete. In most cases, these materials create a finer pore size distribution and lower ionic concentration, which leads to higher electrical resistivity than in normal Portland cement concrete [Whiting et al., 1993].

The relation between cementitious materials and electrical resistivity has been shown in 'Fig. 4' obtained from samples NO. 1,2,3 and 4.

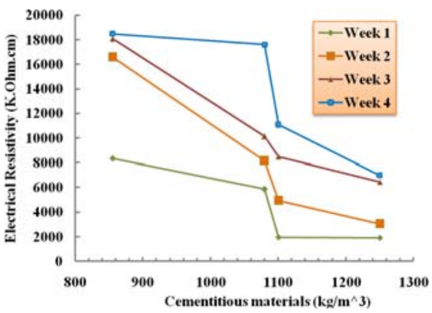

Figure 4. Relation between cementitious materials and electrical resistivity

Concerning the increase of cement content, it seems that decreasing the aggregate content decreases the electrical resistivity in concrete.

3.2.3 Effect of Different types of Pozzolanic Materials

According to relatively high w/c=0.5 in this study, there are some cappilary pores in cement paste. Because of a low cement content, even by a complete hydration process, there would not be sufficient CH for applying the whole pozzolns, considering the high content of pozzolanic materials. Therefore a considerable amount of pozzolanic materials remains non-reactive in the paste and it must be expected a physical effect not chemical; the pores have been filled by non-reactive pozzolans, so grading of non-reactive pozzolans becomes more important.

Comparison between resistivity of silica-fume, metakaolin and combination of them has been shown in ‘Fig. 5’ obtained from samples NO. 1 (Silica Fume+Metakaolin), 5 (Metakaolin), and 6 (Silica Fume).

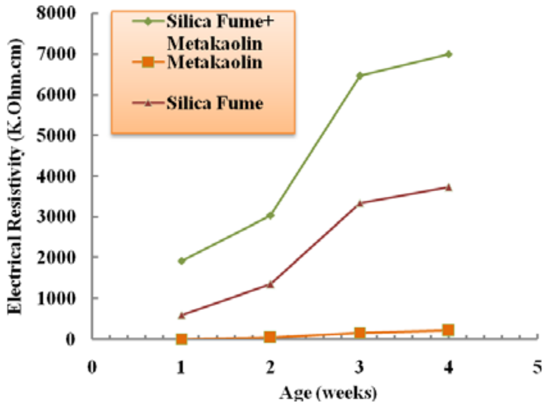

Figure 5. Comparison between resistivity of silica-fume, metakaolin and combination of them

In this research, optimum amounts of pozzolanic materials were found in each sample (about 37% and 16% by weight of cementitous materials for silica-fume and metakaolin respectively). Silica-fume and metakaolin separately has lower enhancement in electrical resistivity rather than their combination, however silica-fume is more efficient than metakaolin. This is shown in Fig 5.

Silica fume has a better effect on improving electrical resistivity than metakaolin for its finer particles and when using a combination from both pozzolans, there would be another grading beside the aggregate grading merely, so blank spaces like capillary pores will be filled more because of better physical role of non-reactive pozzolans.

4 CONCLUSION

In this study, the fundamentals of electrical resistivity have been reviewed and a concrete mix proportion with ultra-high electrical resistivity has been found. The electrical resistivity of concrete is a measure of its ability to resist passage of electric current and ionic migritaion within the concrete.

In general, following factors seem to be effective for increasing the electrical resistivity of concrete:

- Since cement paste has higher conductivity, limiting the amount of cementitous materials would be effective
- Optimum combination of silica-fume and metakaolin has been deduced from presented review instead of applying them seperately.
- Hot water curing may be useful to achieve higher values of electrical resistivities.
- For achiving higher electrical resistivity, effect of physical parameters are significant like the chemical parameters, too.

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